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PERFORMANCE OF A HIGH-SPEED SPECTROGRAPHIC SYSTEM.(U)

SEP 57 W B PLUM , E C INN , W J PARKER

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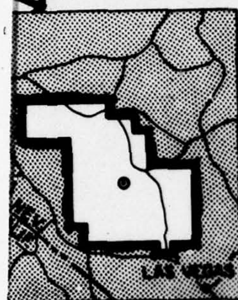

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PERFORMANCE OF A HIGH-SPEED SPECTROGRAPHIC SYSTEM

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OPERATION PLUMBBOB—PROJECT 8.3a

PERFORMANCE OF A HIGH-SPEED SPECTROGRAPHIC SYSTEM

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ABSTRACT

A high-speed streak spectrographic system with a time resolution of about 100 μsec, which is the prototype of the instrumentation to be used for obtaining early-time spectra of bomb light during Operation Hardtack, has been field tested. The results obtained were highly satisfactory, especially with regard to sensitivity at low light levels. The results thus indicate that the possibility is good for obtaining spectra with reasonable optical density during Operation Hardtack.

FOREWORD

This report presents the preliminary results of one of the 43 projects comprising the Military Effects Program of Operation Plumbbob, which included 28 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the Military Effects Program.

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PERFORMANCE OF A HIGH-SPEED SPECTROGRAPHIC SYSTEM

INTRODUCTION

The objective of this Plumbbob project was to field test a high-speed spectrographic system being designed for use during Operation Hardtack for very-high-altitude detonations.

The major features of the time-resolved spectrum of bomb light associated with the first thermal pulse in nuclear detonations at low altitudes have been adequately identified from results obtained by the Naval Research Laboratory (NRL) in previous test operations. These results have contributed much toward an understanding of the phenomenology of the fireball and the nature of the surrounding disturbed atmosphere. In view of the proposed nuclear detonations at very-high altitudes (100,000 feet and 250,000 feet) during Operation Hardtack, similar high-speed spectroscopic measurements at early times will be made. It is expected that the latter measurements, as well as others planned for that operation, will provide basic technical information required for assessing the effect of varying atmospheric conditions on nuclear detonations.

Inasmuch as the spectroscopic measurements during Operation Hardtack will be carried out on high-flying aircraft (about 45,000 feet), modifications in the conventional NRL-type instruments and in techniques have been anticipated, these being necessitated by stringent conditions under which the spectroscopic measurements will be made. However, on the basis of past performances of the conventional NRL-type instrument for obtaining good streak bomb spectra, it was desirable to maintain as close as possible the same spectroscopic specifications for the instrument planned for use during Operation Hardtack. Thus, the spectrograph selected was the Hilger small quartz spectrograph, Model E484. To obtain time-resolved spectra with a resolution of about 100 μsec, it was also planned to use a film-drive mechanism somewhat similar to NRL's. A description of the above two high-speed spectrographic systems is given under INSTRUMENTATION.

In accordance with arrangements made by AFSWP with NRL, one of the latter's high-speed spectrographs has been made available to NRDL. Thus, in Operation Plumbbob, by taking bomb spectra simultaneously with both instruments, a comparison can be made of the performance of one instrument relative to the other.

The performance of a high-speed spectrographic system can best be assessed on the basis of its ultimate sensitivity and sharpness of the photographed discrete spectra. Clearly, the ultimate sensitivity depends on the brightness of the spectrograph and speed of the film. The use of any pre-slit optics that may be required to increase the field of view of the spectrograph will necessarily reduce the light level at the slit of the spectrograph. Hence, the ultimate sensitivity must be high enough so that the effective attenuation introduced by the use of any pre-slit optics will not reduce the light level beyond the ultimate sensitivity of the spectrograph. On the other hand, for cases of high light levels, it may be necessary to introduce sufficient attenuation by the use of pre-slit optics, so that the optical density of the spectrum will be contained within the latitude of the film.

In general, the analysis of a discrete spectrum to identify the constituents can be made unambiguous only if the wave lengths of the lines can be measured with an accuracy

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commensurate with the resolution and dispersion of the spectrograph. This, in turn, will depend on the sharpness of the spectral lines. Since much of the reduced quality of photographed discrete spectra arises from defocusing of the image in the region of the focal plane of the spectrograph, it is clear that the performance of high-speed spectrographic systems depends a good deal on the precision with which the moving film can be constrained to always remain in the focal plane of the spectrograph.

In view of the above, both the NRDL prototype high-speed spectrographic system and the NRL system were field tested during Operation Plumbbob. It was expected that information would be obtained from this field test on the ultimate sensitivity of this spectrographic system, the maximum attenuation permissible by pre-slit optics, quality of the spectra obtained, consistency and reliability with which the high-speed spectrographic system operates, and dynamic range. Furthermore, bomb-light spectra obtained in this field test should be extremely useful for comparative purposes in the final analysis and interpretation of results from Operation Hardtack.

INSTRUMENTATION

NRL High-Speed Spectrograph This instrument is an f/6.6 quartz-prism spectrograph in a Young-Thollon arrangement, with chromatically corrected quartz-lithium fluoride collimator and camera lenses. By the use of a field flattener lens, the focal plane of the spectrograph is flat. The film, 70 mm wide, 100 feet long, and perforated, is pulled through and constrained to move at top speed of about 60 ft/sec in the focal plane. Thus, the running time at this speed and for 100 feet of film amounted to somewhat less than 2 seconds. The film is wound on a takeup spool driven by a $^3/_4$-hp synchronous motor. The spectrum is dispersed along the width of the film, the practical spectral range being from about 2,500 A to 6,500 Å. Timing marks, 1 msec apart, are photographed on one edge of the film. Agastat relays are used to start the film-drive motor and are adjusted so that the spectrum is recorded at zero time when the film reaches its maximum speed.

Since early-time spectra with 100-μsec time resolution are desired from Operation Hardtack, the slit of the NRL spectrograph is 15 microns wide and 2.0 mm long, the latter length giving the required 100-μsec time resolution on the moving film for speeds of about 60 ft/sec. Also, in order to have available maximum sensitivity, it is planned to use perforated 70 mm Tri-X film. For wave-length calibration, the mercury spectrum was photographed prior to that of the bomb light.

NRDL High-Speed Spectrograph The basic instrument in the NRDL prototype system is the Hilger small quartz spectrograph, which has an aperture of about f/10, a Cornu prism, and a flat focal plane. The spectral region covered is from 1,850 Å to 8,000 Å, dispersed over about 8.5 cm. The film-drive mechanism consists of a takeup spool mounted directly on the shaft of a $^1/_4$-hp synchronous motor. Thus, the 70-mm unperforated film is pulled upwards from a film magazine located below the spectrograph, the film being constrained to move in the focal plane. In this arrangement the film speed is about 32 ft/sec. The time required to reach this speed is about 0.5 seconds. At this film speed and for 100 feet of film, the running time is about 3.5 seconds. Timing marks are photographed on one edge of the film every 500 μsec.

To obtain time resolution of about 100 μsec, the slit length was adjusted to 1 mm. For higher time resolution, the slit length was made proportionately smaller. The slit width was adjusted to about 0.015 to 0.020 mm. In view of the film used, 70-mm-wide Tri-X film, the spectral range was limited to about 2,100 to 8,000 Å. Spectra of mercury nitrogen gas, air, and hydrogen were photographed for wave-length calibration, prior to

the photographing of the bomb light. In Table 2.1 is given a comparison of the approximate dispersion and spectral resolution of the NRDL and NRL spectrographic systems.

TABLE 2.1 COMPARATIVE DISPERSION AND SPECTRAL RESOLUTION OF THE NRDL AND NRL SPECTROGRAPHS

Wave length	Dispersion		Resolution	
	NRDL	NRL	NRDL	NRL
Å	Å/mm	Å/mm	Å	Å
5,800			20	20
5,200	210	202		
3,650	66	60	<4	<4
2,700	32	23	<2	<2

SHOT PARTICIPATION

The high-speed spectrographs were aligned with respect to ground or air zero. At about H minus 2 hours, the films were removed from the film storage refrigerator and allowed to warm up to ambient temperature. At about H minus 1 hour, the spectrograph film magazines were loaded and then secured to the respective spectrographs. The first few feet of the film were used to photograph the calibration spectra. At H minus 15 minutes, the electronics for the timing markers were turned on, this being activated by the H-minus-15-minute EG&G timing signal. The Agastat relays controlling the power to the film-drive motor were activated at H minus 1 second from the EG&G timing signal. Thus, the film-drive motor was started just prior to zero time, so that the bomb-light spectra would be photographed when the film was at about maximum speed. The exposed films were developed in D-19 for 10 to 15 minutes, fixed for 15 to 20 minutes, and washed for 25 to 30 minutes.

Lassen. For this shot both the NRDL and NRL spectrographs were operated. No pre-slit optics were used in either system. Since air zero was about 14 miles away and since the yield was predicted to be very low (0.4 to 0.8 kt), the irradiance level at the spectrograph would be very low, being about an order of magnitude lower than sunlight. Thus, the results of this shot should give a fair indication of the ultimate sensitivity of the high-speed spectrographic systems.

Wilson. On this shot both spectrographs were operated with no pre-slit optics. Since air zero was at about the same location as that for Shot Lassen, it was expected that the results from this shot would be indicative of the performance of the spectrographic systems for a somewhat higher level of irradiance, in view of the predicted yield of 2 to 12 kt.

Priscilla. Only the NRDL high-speed spectrograph was used on this shot, again with no pre-slit optics. Since the predicted yield was about 40 kt, it was expected that not only an intense spectrum would be obtained but also a longer duration first pulse. Thus, from such a spectrum it would be possible to determine the sharpness of the discrete portion of the spectrum over the whole spectral region, as well as over the duration of the first pulse.

Diablo. Since this was a tower shot, it was felt that by focusing the image of the fireball on the slit of the spectrograph it would be possible to test the performance of the high-speed spectrograph for higher time resolution. A quartz lens was mounted in front of the slit of the NRDL spectrograph, and the slit length was adjusted to about 0.25 mm, giving a time resolution on the film of about 25 μsec. No pre-slit optics were

used on the NRL spectrograph. Ground zero was about 15 1/2 miles away, the predicted yield 11 to 13 kt.

John. Since the altitude for air zero for this shot was about 19,000 feet, it was decided to photograph the spectrum under conditions that would tend to simulate the VHA shot planned for Operation Hardtack. A quartz lens was used again with the NRDL spectrograph, which effectively increased the field of view of the system to about 12 degrees (total angle). With this arrangement the irradiance at the slit of the spectrograph for this shot was estimated to be somewhat less than a tenth that of sunlight. The slit length was adjusted to 1.0 mm, giving a time resolution of 100 μsec. No pre-slit optics were used on the NRL spectrograph. Ground zero for this shot was about 15 3/4 miles away, the predicted yield about 1.7 kt.

RESULTS

Lassen. Although both spectrographs operated as expected, no results were obtained from this shot. However, since the weapon yield fell far below the predicted yield of about 0.4 to 0.8 kt, the negative results were not surprising.

Wilson. Excellent discrete spectra were obtained from both spectrographs on this shot. Comparison of the spectra obtained with both spectrographs appeared to indicate a somewhat greater sensitivity of the NRDL spectrograph, compared to the NRL spectrograph. Furthermore, the spectrum obtained with the latter spectrograph appeared to have some undesirable scattered light, whereas no evidence of this was found in the other.

Priscilla. Extremely good results were obtained in this shot. The discrete spectrum obtained was intense, clear, and relatively sharp, representing perhaps the optimum possible for a spectrographic system of this type (NRDL).

Diablo. Both spectrographs operated very well on this shot. Although the spectra obtained were different from the previous shots, with little discrete structure, the optical density of the spectra obtained indicated a sensitivity more than adequate.

John. The results obtained from this shot were better than expected. Both spectrographs performed well, and the spectra obtained were intense enough for analysis. In particular, the good results with the NRDL spectrographic system, which operated at a much-lower light level than the NRL spectrograph, indicated adequate sensitivity. Although the optical density of the spectrum obtained with the NRDL spectrograph was not very high, it was certainly sufficient for analysis of the discrete portions of the spectrum.

DISCUSSION

With the exception of Shot Lassen, it appeared that the NRDL high-speed spectrographic system performed very well in giving positive results. The spectrum from Shot Priscilla indicated exceptionally good-quality discrete spectra for a moving-film type of spectrograph. It is clear that such good spectra will permit a less ambiguous analysis of the discrete parts of the spectrum.

The results obtained on Shot John with the NRDL spectrograph were very encouraging. It was expected that the irradiance level at the slit would be somewhat less than a tenth that of sunlight and would approach the limit of sensitivity of the system. However, a satisfactory spectrum was obtained, thereby indicating that the ultimate sensitivity had not been exceeded.

The results indicated that the NRDL spectrographic system performed as well, if not somewhat better, than the NRL instrument. This is based on a comparison of sensitivity, i. e., the NRDL system appeared to be somewhat more sensitive. Furthermore, the amount of scattered light in the NRDL instrument was lower than in the NRL instrument.

However, with respect to quality of the spectra, there appeared to be little difference between the two.

CONCLUSIONS

It is evident from the results obtained that the performance of the NRDL high-speed spectrographic system was satisfactory. It apparently has adequate sensitivity, and based on this, it is felt that there will be better than a good possibility of obtaining good spectra during Operation Hardtack on the high-altitude detonations.

RECOMMENDATIONS

No recommendations are being made on the basis of the results obtained during Operation Plumbbob.

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